

# CASSINI SPACECRAFT ACOUSTIC FLIGHT AND TEST CRITERIA

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## ABSTRACT

Acoustic measurements from eight Titan IV flights, and an acoustic test of a Cassini simulator and Titan payload fairing (1'1 J'), were used to derive acoustic flight and test criteria for the Cassini spacecraft. The flight and laboratory data were used or modified to account for the following factors: (a) noise spike contamination of flight data, (b) spatial and flight-to-flight variations of flight data, (c) application of a thicker barrier-blanket to the P1.F for the Cassini mission after flight data showed an excessive acoustic environment, (d) effects of locating two Cassini assemblies, the Huygens Probe (HP) and the High Gain Antenna (HGA), near the P1.F, (e) higher thrust of upgraded Titan solid rocket motors (SRMs) for the Cassini mission, and (f) special considerations for acoustic testing of the Cassini spacecraft without the 1'1 J'. An overall sound pressure level of 145 dB was verified for the protoflight acoustic test criteria for the Cassini spacecraft.

## INTRODUCTION

The Cassini spacecraft, shown in Figure 1, is currently under development at the Jet Propulsion Laboratory (JPL) and its suppliers for the National Aeronautics and Space Administration (NASA) to explore the planet Saturn, its rings and its moons. The spacecraft will be launched by a Titan IV vehicle with a Centaur upper stage. As described in three earlier papers [1-3], acoustic data were acquired on prior Titan flights using the same payload fairing (1'1 J') to be used on Cassini but, obviously, with different payloads. These data showed that the maximum internal P1.F acoustic environment occurred during liftoff and were strongly influenced by the launch pad configuration, e.g., minor differences in acoustic levels were observed between the two similar Titan launch complexes (1.C-40 and -41) at Cape Canaveral Air Force Station Test Range (ETR), but were substantially exceeded by levels measured at the Vandenberg AFB/Western Test Range (WTR) site (SLC-4B). Since Cassini is scheduled to be launched from 1.C-41, it was decided to omit WTR data from the database once sufficient ETR data became available.

Like all outer planetary spacecraft, Cassini will require on-board nuclear power because the great distance from the Sun precludes the use of solar power. Specifically, electric power will be provided by three radioisotope thermoelectric generators (RTGs) of essentially identical design to those used on Galileo and Ulysses spacecraft. However, the Cassini vibration responses to the acoustic environment at the RTG mountings are expected to exceed those of its predecessors, requiring either RTG redesign and requalification or reduction of the Cassini environment. NASA and JPL concluded that acoustical attenuation would be the most cost effective solution. Thus a program was initiated to reduce the acoustic environment applied to Cassini [4-8]. However, acoustic reduction was required over only a relatively limited portion of the spectrum, namely, the 1/3 octave band (OB) range of 200-250 Hz.

## FLIGHT DATA SUMMARY

Previous summaries included liftoff internal 1'1 J' acoustic data from Titan IV Flights K-1, -4, -7, -9, -10, -19, -21, and -23 launched from ETR. A total of 22 internal P1.F acoustic measurements have currently been acquired on these eight flights. Of these, 17 microphones were attached to the P1.F, while five were supported off the Centaur forward skirt just below the spacecraft. The 22 measurements include 8 repeat measurements on subsequent flights.

Three additional K-4 microphones were supported on 20 inch standoffs from the P.I.F. On average, acoustic data from these three standoff microphones were observed to be about 2 dB less than P.I.F. surface data. However, the number of standoff measurements was deemed to be insufficient for the purpose of reducing the acoustic criteria, and the use of the 22 measurements is considered conservative for the derivation of the acoustic flight and test criteria.

As previously described in [1], liftoff acoustic data from FTR were particularly susceptible to electrical noise spikes. A special procedure was developed to remove the effects of this contamination from data for the first six flights [9], while standard editing methods were used on the last two flights prior to spectral analysis [10].

Envelopes over the 17 maximax P.I.F. and the 5 maximax Centaur acoustic spectra were drawn, resulting in the heavy lines of Figures 2-3. Statistical analyses were also performed on all 22 spectra. Figure 4 shows the mean value and 95 percent upper tolerance limit, with 50 percent confidence, based on statistical analysis of the 22 spectra of Figures 2-3, assuming a normal distribution of sound pressure levels (SPLs) for each 1/3 OB. The use of P95/50 statistics for deriving vibroacoustic criteria from flight data has been a USAF and NASA tradition for many years.

## ACOUSTIC TEST DATA SUMMARY

**Flat Panel Results.** A test program was initiated to determine if an increase in acoustic blanket thickness and/or the addition of a sound barrier could achieve the desired reduction of acoustic loading applied to Cassini and its RTGs. An elaborate series of flat panel tests were first implemented to determine if either or both of these solutions could produce the needed attenuation of 3 dB or more in the 200-250 Hz bands [6,7,11]. Testing was necessary because the application of acoustic theory to this problem was severely limited due to an inability to account simultaneously for twin factors of sound absorption and transmission. Flat panel results indicated that only one of the tested configurations could achieve the desired reduction without a substantial increase in payload liftoff weight, namely, a 6 in. blanket having a density of 0.6 lb/ft<sup>3</sup>, plus a 0.043 in. thick plane barrier having a surface density of 0.44 lb/ft<sup>2</sup>, for an overall surface density of 0.74 lb/ft<sup>2</sup>.

The standard Titan IV 3 in. blanket having a density of 0.6 lb/ft<sup>3</sup>, for an overall surface density of 0.15 lb/ft<sup>2</sup>, was also tested since blankets of this design were installed during flights when acoustic measurements were made.

**Cassini Simulator/P.I.F. Reverberant Test Procedure.** Unfortunately, the attenuation was needed in the frequency range (200-250 Hz) dominated by the ring frequency of the cylindrical portion of the P.I.F. Thus there was no guarantee that flat panel results would be directly applicable to the Cassini installation. As a result, P.I.F. tests were deemed necessary to demonstrate that adequate reduction was achievable under realistic Cassini conditions. Fortunately, the timing of P.I.F. blanket tests coincided with vibroacoustic testing of the Cassini partial development test model (PDTM), the simulator shown in Figure 5, which simultaneously permitted the determination of acoustic attenuation effects on the structural response of spacecraft and component simulators [11,12]. Unlike the partial-DTM test in its P.I.F., the forthcoming protoflight acoustic test on the actual Cassini spacecraft in the JPL reverberant chamber will not utilize a P.I.F. Thus special attention is required to account for acoustic loads expected to cause higher spacecraft vibration response, especially loads applied to the Huygens Probe (HP) and the High Gain Antenna (HGA) as determined from partial-DTM/P.I.F. testing. In addition to determining the acoustic transmission/absorption of the 3- and 6-in. blanket configurations, the other objectives of partial-DTM testing included:

- Determination of fill effects of having the HP and other Cassini elements in close proximity to the P.I.F.
- Evaluation of the effects of having the HGA separate the biconic section from the cylindrical section of the P.I.F.
- Determination of the effects of percentage blanket coverage on acoustic attenuation.
- Evaluation of the effects of tuned vibration absorbers (TVAs) on the structural response of RTGs.

The Cassini partial-DTM was installed in a 60 ft long section of the P.I.F., along with a Centaur-like support structure, and the blanket configuration to be tested attached to the P.I.F. interior for the specified acoustic test run, as shown in Figure 5. This assembly was installed in the Reverberant Acoustic Laboratory facility located at Lockheed-Martin Astronautics in Denver, CO, where acoustic noise from air modulators was applied to the P.I.F. exterior. A sketch of the 8 exterior and 27 interior microphone locations appears in Figure 5. A total of 72 accelerometers and 4 triaxial force gages were also installed on or in the Cassini partial-DTM structure. Data from some of these transducers has been reported elsewhere [5-8,11,12]. For the Cassini mission, it was intended that the thicker barrier-blanket be installed on the P.I.F. interior in the vicinity of the major portion of the spacecraft only, rather than complete P.I.F. coverage, in order to save weight while still being locally effective.

Although generally similar, there are important differences between the acoustic environments applied to the

PIF exterior during flight and during a reverberant acoustic chamber test. Also, there is some variability between reverberant test runs, mainly due to difficulties in achieving perfect acoustic test control. To avoid having potential errors influence the evaluation of the 6 in. barrier-blanket, and the prediction of the flight environment using the thicker configuration, the following procedure was used in processing the measured acoustic data:

- (1) For each test run, all microphone data were analyzed twice, first using a constant resolution bandwidth of 4 Hz up to 2 kHz, and then using 1/3 OBs with center frequencies ranging from 31.5 Hz to 4 kHz.
- (2) For each run, the average 1/3 OBSPI., plus the over-rail (OA) SPI., for the six external control microphones was computed for each 1/3 O11, and the difference taken between this average and the external acoustic test specification. This difference is called the external correction.
- (3) For each run, the 1/3 OBSPI.s from 15 internal microphones were averaged and adjusted using the external correction of Step 2. The average 1/3 OB SPI.s are called the internal adjusted spectrum.
- (4) To predict the additional acoustic attenuation of the thicker configuration, the difference was taken between the internal adjusted acoustic spectra of Step 3 for the applicable pair of test runs, i.e., (a) the original 3 in. flight blanket, and (b) the 6 in. Cassini barrier-blanket.
- (5) To establish the revised Cassini flight acoustic criteria using the thicker configuration, the difference of Step 4 was subtracted from the original P95/50 flight acoustic criteria shown in Figure 4.

Experience has shown that acoustic fill effects can cause a substantial increase in the local acoustic environment applied to structural assemblies which are close to the PIF [13]. The HP is the closest of these assemblies, being approximately 34 in. from tile PIF surface. The two methods of determining fill effect are (a) an analytical formula derived from a recently revised theory [13], and/or (b) the direct measurement of the SPLs in the gap.

As seen in Figure 5, the Cassini HGA effectively separates the biconic section of the PIF from the cylindrical section, i.e., separating the PIF cavity into two volumes. Thus it would not be surprising to find two distinct acoustic environments for these volumes, both of which apply fluctuating pressure to opposite sides of the HGA with the structural loading dependent on the pressure cross-spectrum across the HGA. Coherence data [14-16] for a microphone pair on opposite sides of the HGA close to the structure, i.e., M4 and M6 in Figure 5, show low coherence (except at 43 Hz), which indicates that the two acoustic fields act independently and the two spectra should be root sum squared. At 43 Hz, the coherence is fairly high and the phase angle is nearly zero, indicating the instantaneous pressures should be subtracted and the loading reduced.

**Cassini Simulator/PIF Reverberant Test Results.** The raw acoustic test data was processed in accordance with Step 1-5 to provide the desired revision to the Cassini flight acoustic criteria. Figure 6 shows the internal adjusted spectra for the tests of the 3 in. flight blanket, and the 6 in. Cassini barrier-blanket (which was installed in the vicinity of the spacecraft) and the 3 in. blanket elsewhere. The additional acoustic attenuation provided by the thicker configuration was obtained by taking the difference and subtracting it from the P95/50 flight spectrum of Figure 4 in order to predict the Cassini P95/50 internal flight spectrum shown in Figure 7.

To determine the fill effect for the Huygens Probe, Microphone 11 shown in Figure 5 was located in the 28 in. gap between the center of the HP and the PIF. It malfunctioned during the test of the 6 in. barrier-blanket, making a direct measurement impossible, but fortunately, the revised analytical fill theory [13] could be substituted.

As observed in Figure 5, the HGA effectively divides the PIF cavity into two volumes, i.e., the biconic section above and the cylindrical section below the HGA. The flight acoustic data were acquired at locations in the cylindrical section only. Thus it was necessary to obtain acoustic data in both sections during the Partial-DTM/PIF test to ascertain if higher or lower SPLs existed in the biconic section. If higher levels were found, then an increase in the Cassini acoustic test criteria would be justified over that determined from previous flight data. For application to Cassini spacecraft acoustic testing, data for the two acoustic fields from the test of the 6 in. blanket were compared. Spectra for the three microphones within the biconic section (M2-4) were averaged and compared with the spectral average from 15 microphones in the cylindrical section. Acoustic under-testing of the Cassini spacecraft will be avoided by increasing the P95/50 flight spectrum of Figure 4 by this difference. The avoidance of HGA under- or over-testing is also dependent on the pressure cross-spectrum across opposite sides of the HGA during the forthcoming Cassini spacecraft acoustic test.

## CASSINI SPACECRAFT ACOUSTIC FLIGHT AND TEST CRITERIA

In order to provide more thrust to the Titan IV vehicle, which is required to permit tile launch of the heaviest

possible spacecraft propellant mass, the previously-used standard steel case solid rocket motors (SRMs) will be replaced by recently-developed more powerful (7 percent) composite case SRM upgrades (SRMUs). This change is predicted to result in a small increase in acoustic levels, less than 1 dB, which must be taken into account before the revised Cassini flight criteria and the Cassini spacecraft acoustic test criteria are derived. In summary, the acoustic flight criteria, and the acoustic test criteria for the upcoming spacecraft test without the PIF, were derived using:

- (1) the P95/50 internal PIF flight spectrum of Figure 4,
- (2) minus the difference between the internal adjusted spectra of Figure 6 to account for the thicker barrier-blanket attenuation,
- (3) plus a 1 dB increase for using the SRMUs for the Cassini mission, resulting in the revised Cassini acoustic flight criteria of Figure 8,
- (4) plus the maximum of (a) the HIP analytical fill effect, and (b) the difference between the two average acoustic spectra across the HGA,
- (5) plus minor "adjustments" needed to provide a smooth test spectrum required by air modulators, resulting in the revised acoustic test criteria for the Cassini spacecraft, also shown in Figure 8.

The test spectrum to be used for the reverberant acoustic test of the Cassini spacecraft without the PIF has a protoflight margin of 4 dB over the FA test spectrum of Figure 8.

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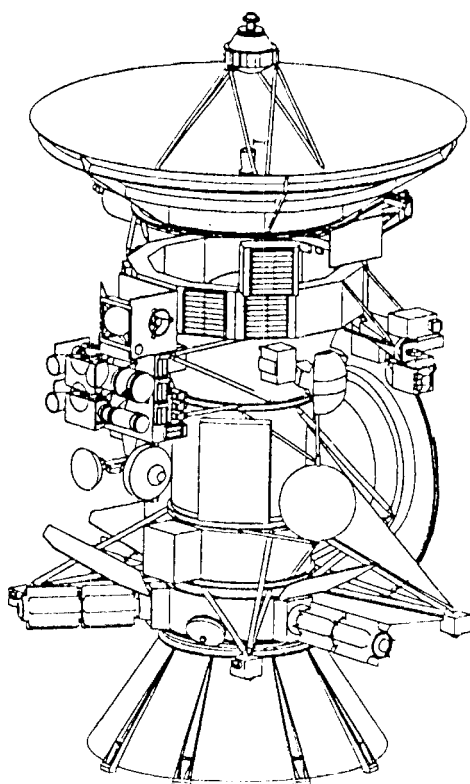


Figure 1: Trimetric View of the Cassini Spacecraft Launch Configuration

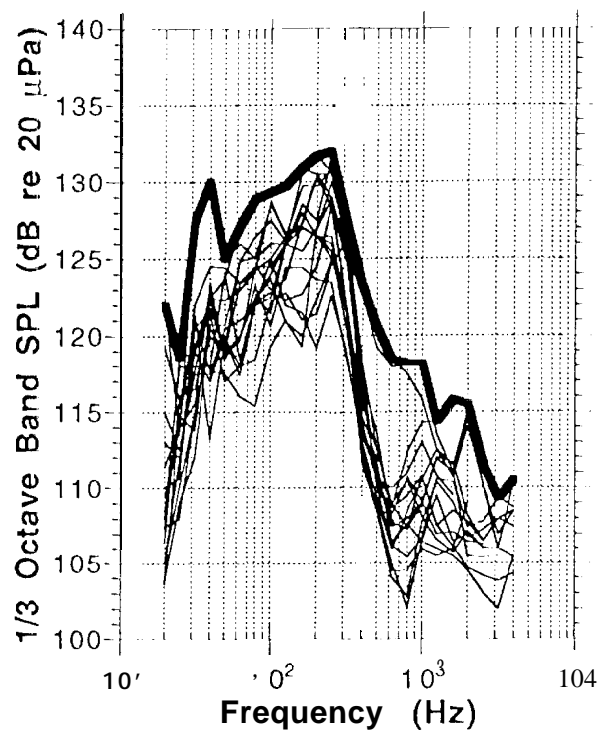


Figure 2: Spectral Envelope of Maximax Acoustic Spectra for 17 Internal Payload Fairing Measurement During Liftoff of Six Flights

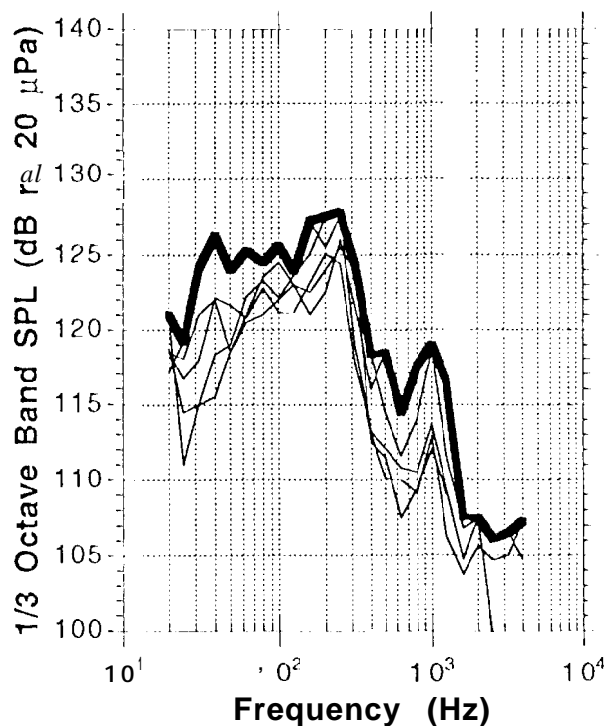


Figure 3: Spectral Envelope of Maximax Acoustic Spectra for Five Internal Centaur Measurements During Liftoff of Five Flights

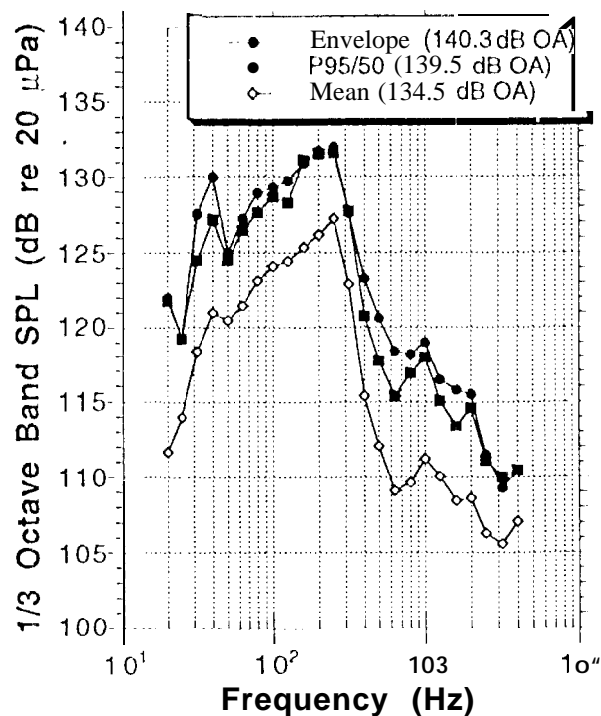


Figure 4: Comparison of Mean, P95/50%, and Spectral Envelope of Maximax Acoustic spectra for 22 Internal P/L/Centaur Measurements from 8 Titan IV Flights

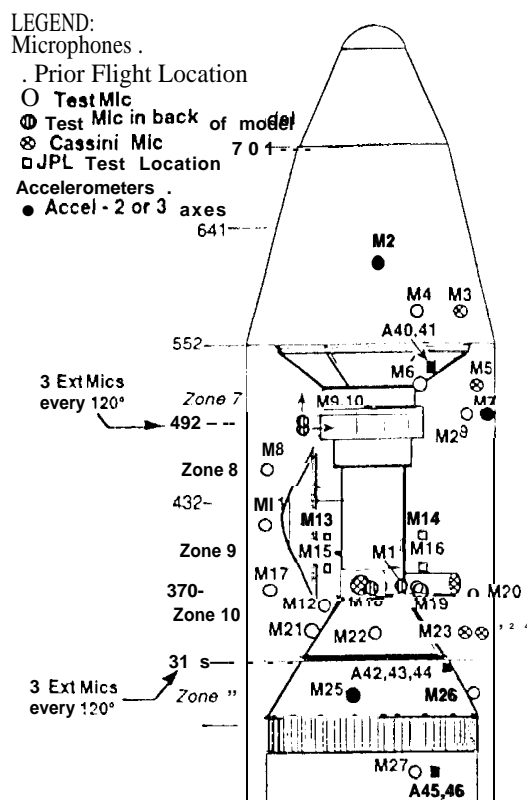


Figure 5: Configuration and Instrumentation Locations for the Partial DTM/PLF Acoustic Tests

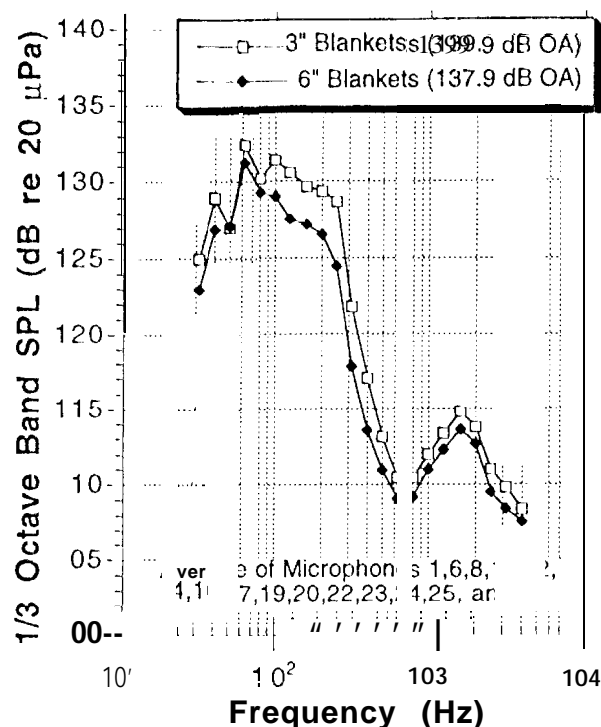


Figure 6: Comparison of Average Acoustic Levels Around the Spacecraft Measured During Testing of the Original 3 inch Flight Blanket and the 6 inch Cassini Blanket

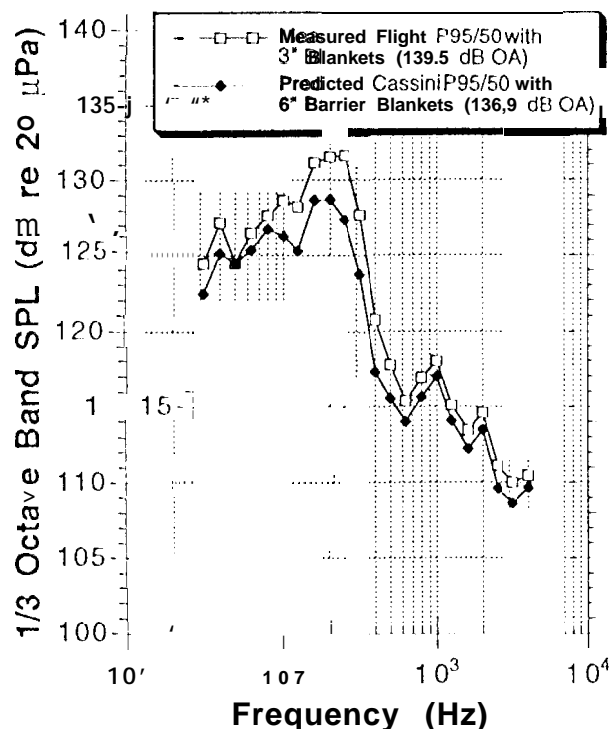


Figure 7: P95/50 Flight Spectrum Adjusted to Account for Cassini 6 inch Barrier Blankets

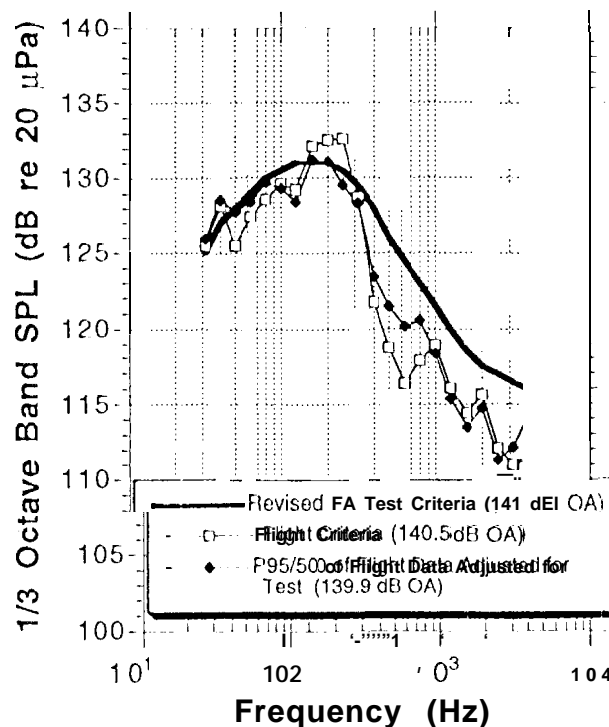


Figure 8: The Cassini Acoustic Flight Criteria and Flight Acceptance (FA) Test Criteria